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Vehicle Thermal Management Simulation at TARDEC

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Outline

- TARDEC/CASSI Introduction
- Why TARDEC Performs Simulation
- Interior Cooling Analysis
- Engine/Underhood Cooling Analysis
- Conclusion

TARDEC - Introduction

- Tank Automotive Research, Development and Engineering Center (TARDEC)
  - Develops, integrates, and sustains the technology for all manned and unmanned DOD ground systems
  - The main Research and Development Engineering (R&DE) organization for ground systems integration and technology
- Consists of Three Major Business Groups:
  - Engineering Business Group
  - Product Development Business Group
  - Research Business Group
    - Includes CASSI (Next Slide)

CASSI ANALYTICS

Concepts
Analysis
Systems
Simulation
Integration

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Why TARDEC Performs Simulation

- Pre-Request For Proposal (RFP) work
  - Need to ensure specifications are technically feasible before issuing RFPs
  - Analysis of Alternatives (AOA) studies
- Evaluation of proposals and oversight of supplier efforts
  - 'Honest Broker' - proposed solutions should be evaluated on a level playing field
  - Verify supplier analyses are reasonable
- Rapid response for field fixes
  - Determine how new equipment will affect vehicle performance
  - Provide initial assessment before starting formal contract process for proposed upgrades
- Analysis for technology demonstrator vehicles
- Direct R&DE efforts through cooperation with industry and universities
  - Form partnerships to direct development efforts in areas of interest to the Army

Interior Cooling Analysis

- Objective: Determine environment in crew cabin during extreme hot conditions
  - Size A/C System
  - Evaluate electronics cooling (will components fail?)
  - Evaluate crew effectiveness/comfort
  - Optimize HVAC Duct Design
- Potential Analysis Scenarios
  - Steady-state
  - Pull down
  - Diurnal cycle (24+ hours)
- Environmental conditions
  - Extreme High Temperatures
    - >125 ºF ambient temperature
    - 1120 W/m^2 solar load
  - Environment: Tunnel or Outdoor

Diurnal Cycle:
Ambient Solar Load and Temperature

Temperatures of Categories A1 and A2 in °C, Solar Radiation (W) in W/m^2

A1	37	35	34	34	33	33	32	33	35	38	41	43	44	47	48	48	49	48	48	46	42	41	39	38	37
A2	33	33	32	32	31	30	30	31	34	37	39	41	42	43	44	44	44	43	42	40	38	36	35	34	33
W	0	0	0	0	0	0	55	270	505	730	915	1040	1120	1120	1040	915	730	505	270	55	0	0	0	0	0

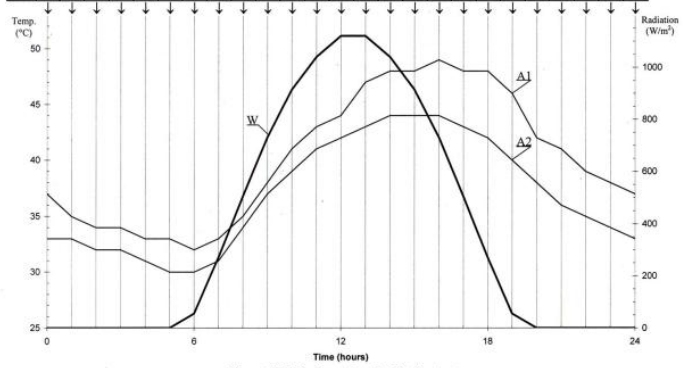
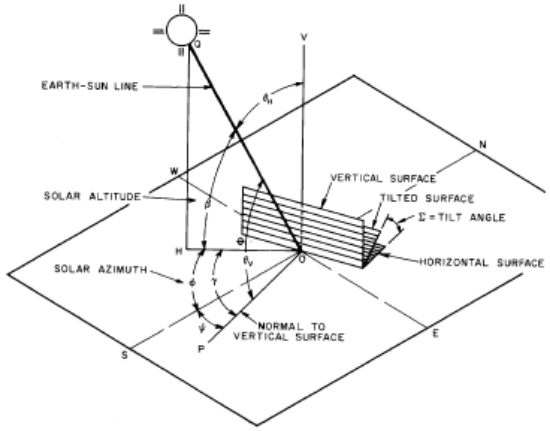


Figure 505.5-1. Procedure I – Cycling test.

Diurnal Cycle: Solar Position



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Interior Cooling Analysis Challenges/Considerations

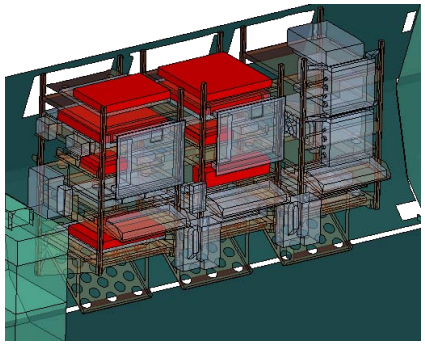
- Vehicle technical data is not always available– especially:
  - Material properties (density, specific heat, conductivity)
  - Cooling system performance specifications (HVAC capacity, flow rates, etc.)
  - Surface properties (emissivity, solar absorptivity)
  - Engine exhaust flow rates and temperatures (underbody heating)
- CAD data may be difficult to obtain or may be outdated
- Difficulties with electronic components:
  - Obtaining reasonable values for heat rejection (duty cycle)
  - Temperature limits– when does failure actually occur?
  - Modeling of internal cooling fans inside electronic enclosures boxes
- Multiple modes of heat transfer (multiple codes?):
  - Need to model environmental heat loads
    - Solar position, irradiation
  - Need to calculate internal and external convective heat transfer
  - Need to model internal advection
  - Need to model thermal conduction and thermal mass

Internal Cooling Analysis Methodology

Model Preparation

Analysis: Iteration Required

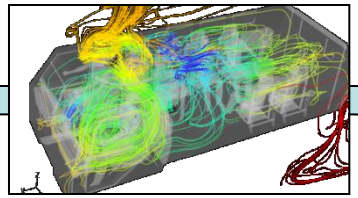
CAD Geometry



Surface Prep
- Prepare surface for CFD Model

Surface Prep
- Build surfaces for Thermal Model

CFD Model
- Calculates advection (air flow patterns)
- Calculates heat transfer coefficients

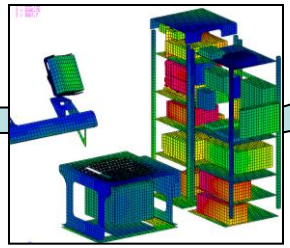


Heat transfer coefficients & Fluid Temperatures

Surface temperatures

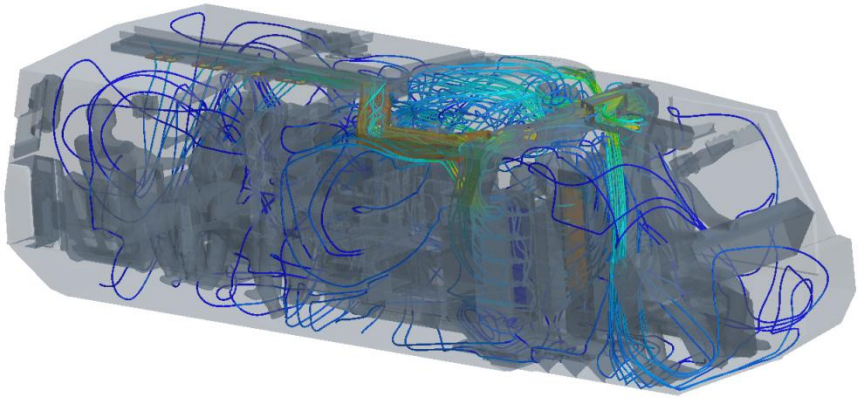
Sub volume Code
- Divides interior into fluid nodes and connected surfaces
- Uses CFD to calculate flow rates between fluid nodes

Thermal Model
- Predicts surface temperatures
- Calculates effects of environmental loads

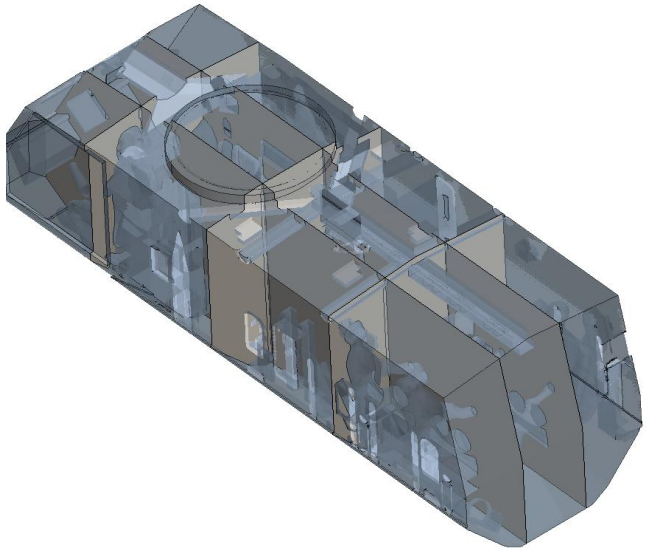


Internal Cooling Analysis: Sub-Volume Approach

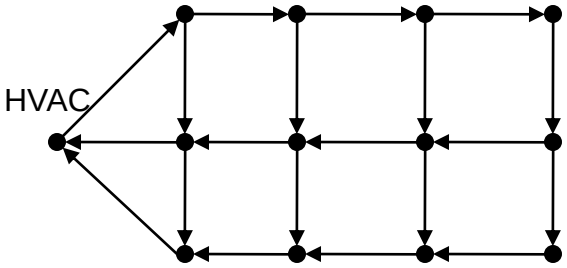
1. Calculate flow field CFD



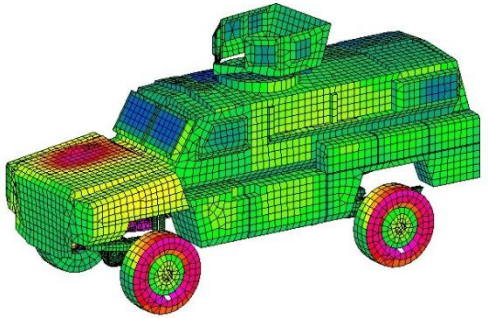
2. Divide domain into sub-volumes



3. Calculate advection between nodes



4. Add advection links to thermal model



Interior Cooling Analysis: Coupling CFD and Thermal Codes

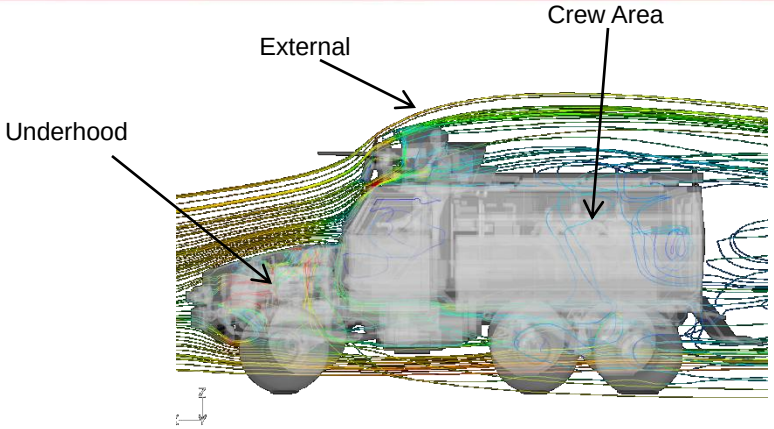
- Why couple CFD with a Thermal Code?

Category	CFD Model	Thermal Model
Geometry	Uses volume elements	Uses surface elements (shells)
	Models actual geometry	Geometry adjusted to model heat paths
	Quick surface preparation (with wrapping)	Surface prepration takes a long time (can't use wrapper)
Setup	Limted material and surface property database	Extensive material and surface property database
Physics	Calculates advection	Advection must be manually setup
	Calculates surface heat transfer coefficients	Convection coefficients based on handbook values
	Cannot perform IR signature analysis	Can be extended to perform IR Signature Analysis
	Manual setup for weather model	Incorporates weather model
	Requires manual setup of solar angle	Calculates solar angle
	Does not calculate terrain effects	Calculates terrain reflection
Run Time	Long run time for transient simulations	Transient simulations run quickly

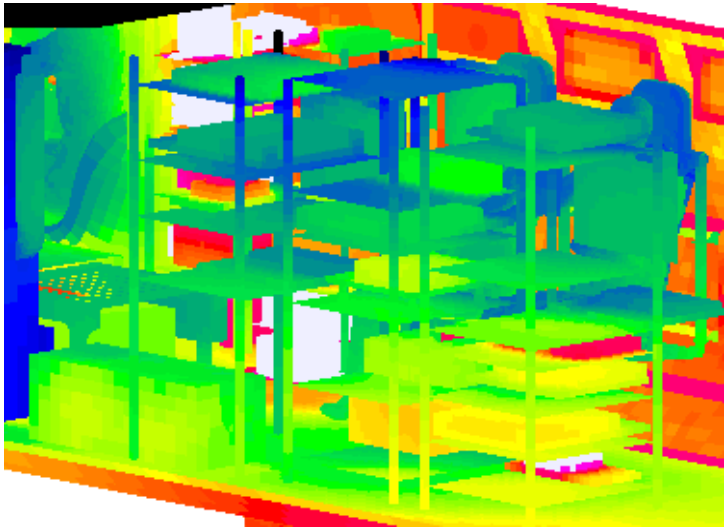
- Coupling allows each code to use it's particular strengths
  - CFD to calculate advection and convection
  - Thermal for environment and radiation effects
- Disadvantage to Coupling:
  - Thermal model requires clean surface with manual cleanup
- Modeling both solids and fluids in one model may resolve this issue, but long transients may still be a challenge

Interior Cooling Analysis: Examples

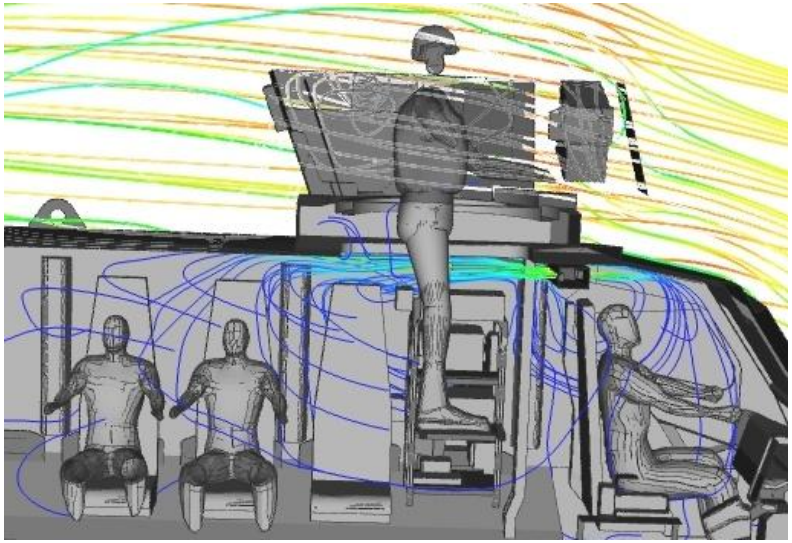
HVAC Duct Design



Exterior Flow Field



Component Temperatures

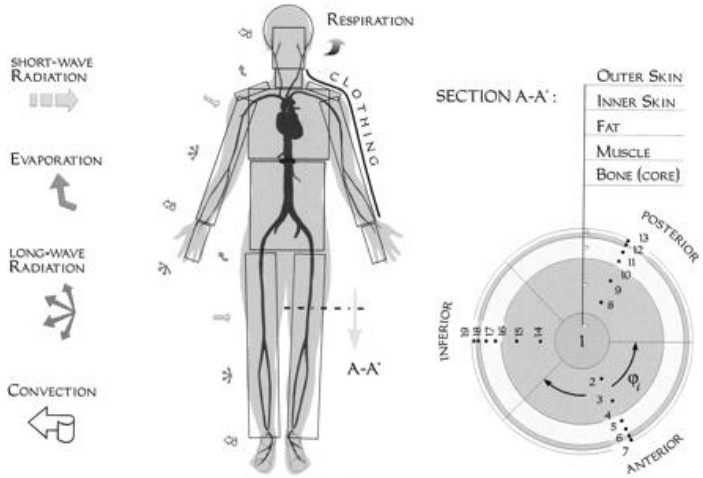


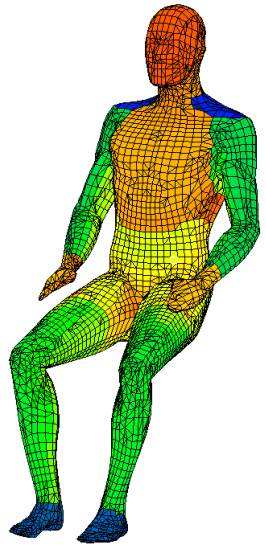
Simulation: Hatch Open

Crew Comfort/Effectiveness Modeling

Enhancement to Interior Cooling Analysis

- Objective: Assess crew's ability to perform mission based on interior environment
- On-going CRADA (Cooperative Research And Development Agreement)
  - TARDEC oversees development and provides some funding
  - GM shares experience and lessons learned
  - Small business develops code and sells commercially
- Soldier Thermal Fatigue Model
  - Based on University of California Berkley model
  - Define metabolic heat rates by role (driver, gunner, commander)
  - "Comfort" index generated from local skin temps and body core temp





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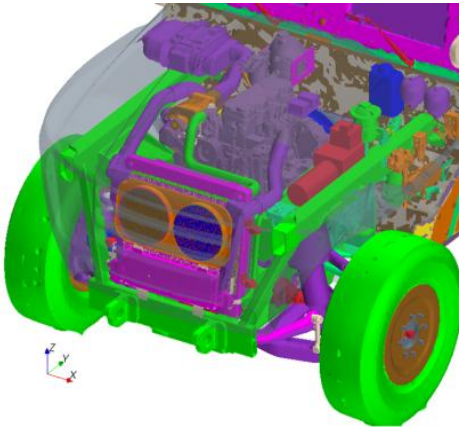
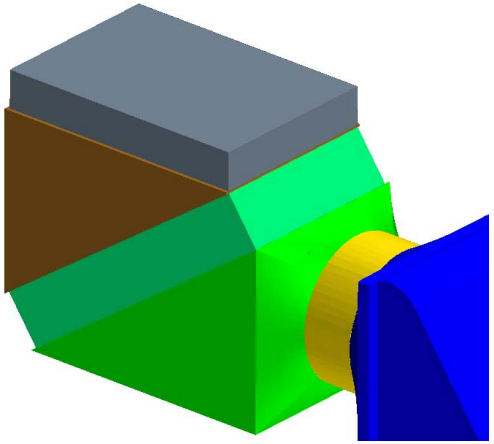
Underhood/Engine Cooling Analysis

- Objective: Assess cooling performance of vehicle
  - Determine ability of system to operate at high ambient temperatures
    - Predict performance
  - Fan Sizing/System Resistance
    - Reduce power requirement
- Analysis Geometries
  - Underhood
  - Cooling Tower
- Extreme operating conditions
  - 125 ºF Ambient temperature
  - High engine and transmission load
    - Full engine power
    - High tractive effort or steep grade



Underhood Geometry

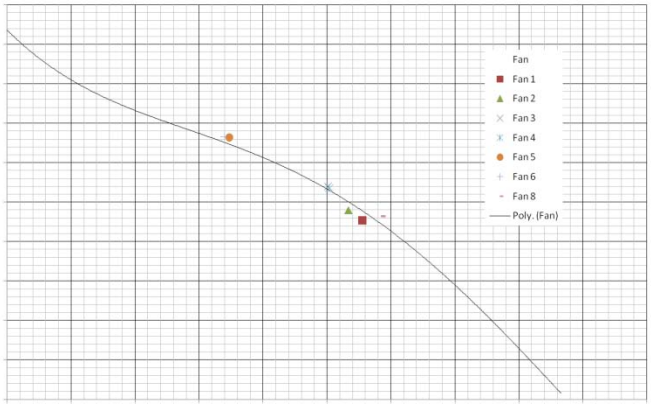


Cooling Tower Geometry

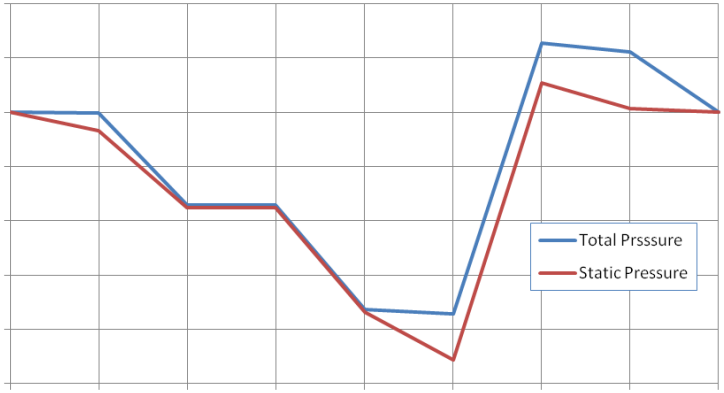
Underhood/Engine Cooling Analysis Challenges/Considerations

- Availability of Data
  - Vehicle Geometry
  - Heat Exchanger Performance
    - Pressure vs. Flow
    - Heat rejection map
  - Heat rejection requirements
    - Often not available early in design phase
    - May not be accurate for legacy vehicles which have been modified
  - Fan Modeling
    - Availability of fan geometry
    - Applicability of CFD code's fan model
      - May not be applicable for vane-axial fan
- Physics
  - thermal or cold flow?
    - Cold flow is useful for validation purposes
    - Including temperature provides more information, but is more difficult to validate experimentally

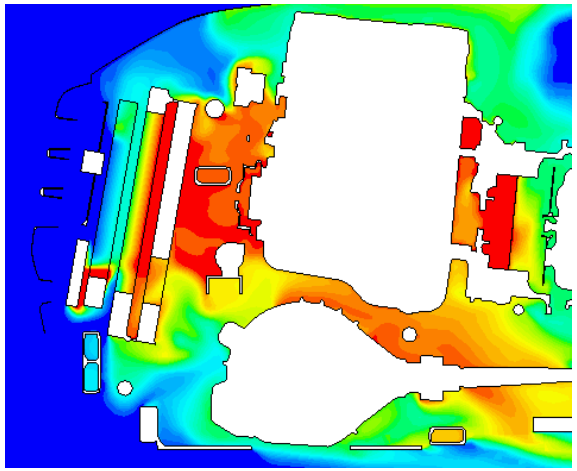
Underhood/Engine Cooling Examples



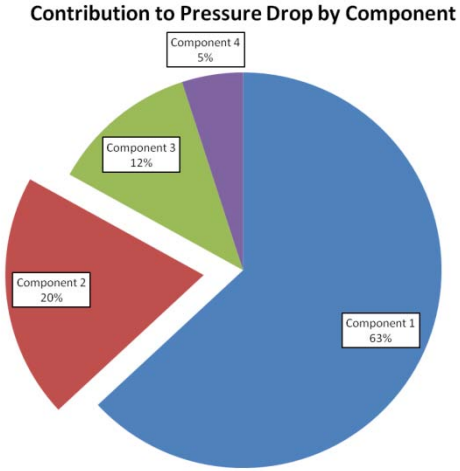
Fan Operating Points/Power Prediction



Pressure Trace Through System



Underhood Cooling



Fan Pressure/Power Budgeting

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Conclusion

- Vehicle thermal analysis plays an important role at TARDEC
- There are two major areas of interest
  - Interior cooling
    - Predicting potential failure of electronic components
    - Sizing HVAC capacity
    - Determining Crew effectiveness/comfort
  - Underhood/Engine thermal analysis
    - Predicting vehicle performance at high ambient temperatures
    - Determining fan/cooling system size
- There are challenges
  - Obtaining reasonable performance data for system components
  - Obtaining CAD Data
  - CAD Cleanup for thermal model vs. CFD model

THANK YOU

Questions?